THREAT AND BATTLEFIELD DAMAGE ASSESSMENT USING 3D IMAGING AND SENSOR FUSION

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ABSTRACT

The proposed technology is a three dimensional (3D) and sensor fusion display for threat and battlefield damage assessment (BDA). The 3D auto-stereoscopic display is implemented for Homeland defense applications in combination with an X-ray scanner that will bring attention to packages with potential threats. Sensor fusion will benefit BDA by providing fused visible and infrared (IR) images of combat vehicles that have been damaged or destroyed on the battlefield.

1. INTRODUCTION

Battle Damage Assessment is a requirement for current and future ground vehicle missions. Three subcomponents of BDA are physical damage assessment (PDA), functional damage assessment (FDA) and target system assessment (TSA). Our proposed technical approach is to provide a visual evaluation for the effectiveness of the target's capability with surveillance systems. The advanced BDA will increase the survivability and lethality of combat systems, and reduce the precision munitions expenditure. The proposed concept system would include a fused image of visible and IR combined with a real-time 3D display that will be tested under field conditions. The system will support real-time BDA by providing fused visible and IR pictures of combat vehicles. This assessment will allow soldiers to identify combat vehicles that have been damaged or destroyed on the battlefield and eventually distinguish civilians from insurgents. The task will be accomplished using the sensor fusion technique for visual and IR imagery. The battle damage assessment with 3D depth perception will be accomplished by using multiple camera views displayed directly using an auto-stereoscopic display. This technology was tested in the lab environment for threat recognition and camouflage assessment. Sensing, assessing, and reporting the success or failure of battle damage (e.g. disabled, damaged, destroyed) of combat vehicles and targets is essential for successful mission accomplishment. Post-strike BDA must be reported to the commanding authority for evaluation and response decision, such as re-attack. The proposed technology will expand the warfighter's perception, situational awareness (SA), and knowledge of the battlefield situation beyond the limits that were available through visual and other sensory perception. Warfighter payoff is the real time damage assessment of combat vehicles, dynamic surveillance, data fusion and 3D visualization.

2. THREAT ASSESSMENT USING 3D DISPLAY

It has been estimated that failures in advanced man-machine systems attributed to "human error", and increasingly to loss of operator SA, and may be as high as 75%. Three dimensional displays will increase SA by allowing a user to see information collected by sensors in a natural environment as opposed to planar images. There are a number of mirror systems which form a real three dimensional image in space of one object in a position which is well separated from another object. One of the major parts of the stereoscopic display used in the VPL is the spherical concave mirror. A spherical mirror can magnify the size of the object being displayed. The paraxial equation for a spherical mirror is shown below in equation (1):

$$\frac{1}{s}+\frac{1}{s'}=\frac{2}{r}, \tag{1a}$$

$$\text{where } r=\frac{f}{2} \tag{1b}$$

Here, s is the object distance from the mirror, s' is the image distance, r is the radius of curvature of the mirror, and f is the focal length of this mirror. The magnification m can be defined as the ratio of the image size to the object size as shown in equation (2):

$$m=\frac{h'}{h}, \tag{2a}$$

$$\text{or } m=-\frac{s'}{s} \tag{2b}$$

Here, h' is the image size, and h is the object size. The magnification can also be defined in terms of the image distance and the object distance. The minus sign indicates that the image is inverted (Ditteon, 1997). A magnified image is obtained with the object distance

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between the focal length and the center of curvature of the mirror. The new 3D display system with a solid fixed focal length mirror used for Homeland defense applications provides magnification up to two times the image size.

The Visual Perception Lab (VPL) at RDECOM-TARDEC proposed the 3D auto-stereoscopic display for various defense applications. This 3D display uses spherical membrane mirror technology. This technology was developed by engineers and scientists of the Department of Mechanical Engineering at the University of Strathclyde, in Glasgow, UK (McKay et al., 1999). The spherical membrane mirror was later implemented in the auto-stereoscopic 3D display by Ethereal Technologies. A vacuum pump is used to shape the mirror membrane to the desired spherical shape. Researchers in the VPL use the large field of view Ethereal display for feasibility studies using 3D. The images for the 3D auto-stereoscopic display can be captured by a stereoscopic camera, or by shifting 2D images in space, or combining pairs of images taken at different times. The pairs of images are downloaded into the computer, and displayed on two LCD screens. The left view image is displayed on the right hand LCD, and the right view image is displayed on the left hand LCD. These images are inverted by the lens and mirror system shown in Figure 1. Another possible application of this technology in some rugged form is a lenticular display for use in vehicles.

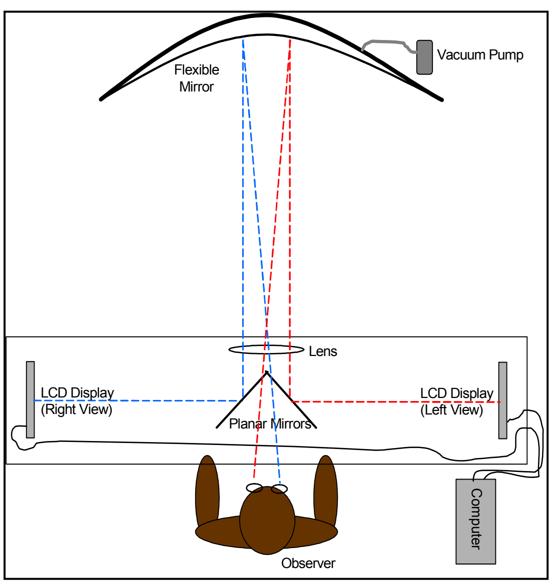


Figure 1: VPL auto-stereoscopic 3D display

In asymmetrical warfare, the civilians are considered targets. There is a need for technology to scan packages and use this 3D system to reduce illegal transport of weapons and potential threats on U.S. soil. This display can be applied to crowd surveillance and screening at public access points. In these times of increased concerns about terrorists and passengers carrying concealed weapons or other harmful items, sensor fusion and 3D displays could be of benefit in alerting guards to potential dangerous passengers. Combining sensor fusion with a 3D display could also improve the recognition rate of guards using cameras that scan crowds for people that are listed in a known terrorist database. We believe that implementing volumetric visible and IR images will improve the recognition rate, because it will provide a more detailed 3D image or thermal properties versus only a 2D visible image of possible terrorization (Meitzler, et al., 2002).

Another important application of a 3D display is improved visualization of potential threats during package scanning. Professor Bob Andrews from Ethereal Technologies is presently working with the Transportation Security Authority (TSA) in Atlantic City and the VPL at RDECOM on implementing the auto-stereoscopic 3D display technology for X-ray package scanning. A set of images was collected from the X-ray scanner at the US Army RDECOM shipping and receiving department. These images were then converted into stereoscopic pairs to be displayed on the auto-stereoscopic 3D display.

Today, safety is implemented by not allowing the RDECOM employee to open any shipment packages without examining it first. A properly trained RDECOM employee must scan the package by using an X-ray scanner, where the image is displayed on the monitor which provides a 2D image of the objects inside the package. As seen in Figure 2 the color depends on the density of the material or object in the package. For instance, a bluish or orange color represents denser or less dense materials respectively. The test image of the faux bomb from the shipping and receiving department X-ray scanner is shown in Figure 2. The image was provided by Mr. Leonard Miles, a contractor at RDECOM shipping and receiving department. This inert bomb was used to test employees on their inspection skills. The 2D X-ray scan shown in Figure 2 does not provide the screener with the depth perception of the object which would have made it easier for them to find harmful items.

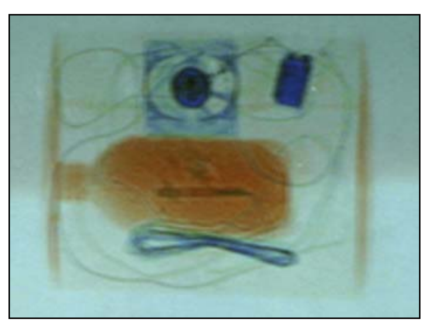
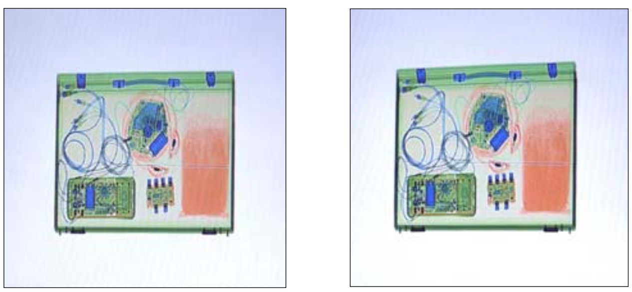


Figure 2: The test image of a mock bomb from the RDECOM shipping and receiving dock X-ray scanner

The information that was received regarding the tactics of the X-ray scanner was further tested in correlation with the 3D display mirror in the VPL laboratory. Figure 3 provides an example of a real set of pictures of a package that was collected from the X-ray scanner. To create 3D images from the X-ray scanner VPL team members captured pictures of questionable packages at different angles in one plane. The images were then placed into a stereoscopic format for the 3D display that would then convert this same image into 3D. The left image is a plain image of a package inside the X-ray scanner. The right image was obtained by raising the same package in the z plane with a piece of Styrofoam, which is invisible to the scanner. The x and y coordinates of the package in the right image were the same as in the left image. As seen in Figure 3 the left and right eye images are distorted somewhat from each other. These images were converted into stereoscopic pairs to be displayed using the auto-stereoscopic 3D display mirror in the VPL. This gives a person depth perception and may increase detection of dangerous material varying from different areas whether in an airport or at a place of business.



(a) Left eye image; (b) Right eye image

Figure 3: The stereoscopic pair of images from RDECOM's shipping and receiving dock

Viewing this pair of images on the 3D auto-stereoscopic display shown in Figure 3 gives a better depth perception of a package. The 3D representation will assist the screener in identifying what the object really is. It will allow the screener to see the information collected by the X-ray machine in a natural 3D environment as opposed to the planar images. The future systems will implement sensor fusion combined with the 3D visualization. The images will be fused digitally to present them through stereopsis. Stereopsis is the process of using our human visual system to extract depth information to build a 3D understanding of a scene. Some people who cannot experience stereopsis will see a flat image, rather than a stereoscopic image. The VPL is planning to do 3D assessment tests that compare images in 2D to 3D of response time and false alarm rates. A 3D test can continue once it is determined that the test subject can experience depth perception.

3. THREAT ASSESSMENT USING IMAGE FUSION

Another component of the proposed technology for BDA is image fusion for Homeland defense applications in which RDECOM's VPL performed a test using a rocket propelled grenade (RPG). Image sets are of a warfighter holding a RPG that were composed of an IR, visible and a fused image arranged side by side as shown in Figure 4 below. A quality rating of the RPG images was given to determine which of the three images provided more detail. We asked test subjects to rate images on a scale from 1 to 3, with 1 being the easiest to detect the RPG. Although the RPG was easily visible in the IR image and most fused images, it was not readily apparent in the visible images. Due to sometimes poor quality of the visible images, the fused images would suffer as well, since they were constructed from the visible and IR images. Future work could strive to develop a smarter enhancement algorithm for image fusion.

(a) IR image; (b) Visible image; (c) Fused images

Figure 4: Images captured of a warfighter holding a RPG by using different image systems

The statistical results of the RPG test were analyzed as seen below in, Figure 5, which shows the subjective quality rate of the RPG in the image versus the sensor type.

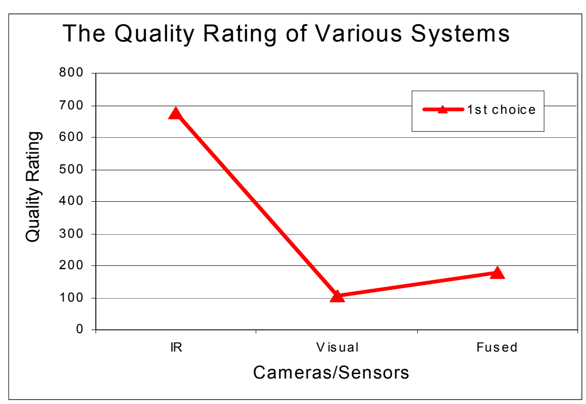
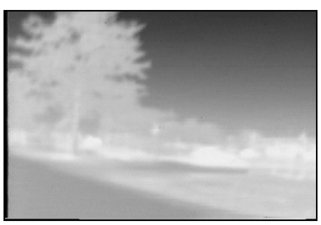


Figure 5: The quality rating of various cameras and sensor systems as seen in Figure 4 images

This graph illustrates that the highest detection rate was achieved using the IR sensor, and the lowest detection rate was found with the visible image. Even though the test subjects chose the IR imagery over the fused for seeing the RPG weapon, they commented on the fact that they preferred the fused image, because it provided more details to the area of interest.

The sensor fusion technique can benefit the post-strike BDA activity, because it can obtain information about combat vehicles that have been damaged or destroyed on the battlefield using IR images. However, a fused image of the battlefield will provide more detail, because it has a wider spectral band. The spectral band for visible light ranges from 0.4 to 0.7 microns. The FLIR FSI digital automatic camera that we used for imaging in the IR part of the spectrum had light wavelength ranging from 2 to 8 microns. The fused image had the combined spectral range of both visible and IR cameras. As an illustration of this fact, Figure 6 (a) shows an IR image of an automobile in a parking lot, (b) shows a visible image of the same scene, and (c) shows the fused IR and visible image of the scene. The fused image was obtained using a customized, in-house Matlab program. Similar to the RPG test, the improved quality of the image in Figure 6 (c) can be easily observed.


(a) IR image;


(b) Visible image;


(c) Fused IR and visible image

Figure 6: Images of a scene with an automobile, captured using different imaging systems

CONCLUSIONS

Maintaining situational awareness, dynamic surveillance, and target development is important for the warfighter. This task will be accomplished through sensor acquisition, data fusion and 3D visualization. The implementation of the integrated image system will support real-time BDA by providing images of combat vehicles with IR signatures. It will enable identification of vehicles that have been damaged or destroyed. The battlefield could be accessed promptly using a 3D display with depth perception capability for accurate BDA. It will expand the warfighter's perception, situational awareness and knowledge of the battlefield situation beyond the limits that were available through visual and other sensory perception. New IR cameras for defense applications are being developed by the FLIR Corporation. In the future we would like to evaluate the AF/256 super sensitive thermal imaging system developed by FLIR Corporation. This system is ideal for medium to long range detection. The unit has the capabilities of detecting a human up to 8 Kilometers in total darkness and in adverse conditions. The heart and soul of the AF/256 is an Indium antimonide infrared detector which offers ultra sensitive imaging and is widely utilized by the United States and NATO countries. This is an ultimate system for BDA, airfield, harbor and critical installation surveillance. The proposed new technologies will utilize joint intelligence estimates provided by a layered sensors approach and will develop BDA to support all fire missions and joint assets. Warfighter payoff will be the real time damage assessment of combat vehicles, dynamic surveillance, image based sensor fusion and 3D visualization. Another important application of a 3D display technology for Homeland defense is improved visualization of potential threats during package scanning. By using the 3D display technology the screeners sees depth in the object. It will allow the screener to see the information collected by the X-ray machine in a natural 3D environment as opposed to the planar images. In the future work we would like to investigate the experiments with sensor fusion further to include magnetic sensors, which will facilitate more accurate BDA. The future systems will implement sensor fusion combined with the 3D visualization.

REFERENCES

Ditteon, R., *Modern Geometrical Optics*, J. Wiley & Sons, (1997).

McKay S., et al., 1999: *Membrane Mirror Based Display for Viewing 2D and 3D Images, Proceedings of SPIE Vol. 3634,* pp 144-154.

Meitzler, T., et al., 2002: Comparison of 2D and 3D displays and sensor fusion for detection, surveillance and telepresence, *Proceedings of SPIE Vol. 5071*, pp 536-542.